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JULIE RIEDEL KELLER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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A NORMATIVE DATA STUDY OF ISOMETRIC NECK STRENGTH

IN HEALTHY, ADULT MALES, AGES 18-35

By

Julie Riedel Keller

A. Joe Threlkeld

(Director of Thesis)

Robert Shapiro

(Director of Graduate Studies)

July 16, 1990

(Date)

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Julie Riedel Keller

The Graduate School

University of Kentucky

1990

A NORMATIVE DATA STUDY OF ISOMETRIC NECK STRENGTH

IN HEALTHY, ADULT MALES, AGES 18-35

THESIS

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science at the University of Kentucky

By

Julie Riedel Keller

Lexington, Kentucky

Director: Dr. A. Joseph Threlkeld

Associate Professor of Physical Therapy

Lexington, Kentucky

1990

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ABSTRACT OF THESIS

A NORMATIVE DATA STUDY OF ISOMETRIC NECK STRENGTH IN HEALTHY, ADULT, MALES AGES 18-35

Isometric neck muscle contraction forces generated during attempted neck flexion, extension, and side bending by sixty subjects were measured using a load cell in order to establish normal ranges for cervical muscle strength. Contraction forces during three trials were collected and measured using ASYST 2.01. Time averaged forces and instantaneous peak forces generated were compared and no significant differences were evident. Measured mean extension forces (236 N) exceeded mean flexion forces (202 N) and mean side bending forces (155 N). Anthropometric measurements correlated poorly with measured cervical forces and are not recommended as cervical strength predictors. Correlations between dominant grip strength and neck strength were sought but no relationship was apparent. Force variability between trials was evaluated with analysis of variance testing, with significance set at $p < 0.05$. Increased forces were generated by successive contractions. Comparisons between right and left lateral neck strength indicated no statistically significant functional asymmetry between the two sides. Six subjects (10%) were randomly selected to return for repeat testing to evaluate test-retest reliability using paired t-tests, and no consistent differences between tests were evident.

Julie Riedel Keller
(Author's Name)

July 16, 1990
(Date)

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CHAPTER 1

INTRODUCTION AND STATEMENT OF THE PROBLEM

INTRODUCTION

Work and leisure activities place great demands for strength, stability and mobility on the neck and trunk musculature. This has been demonstrated in athletes and normal populations for both the cervical spine by Bjelle et al (1981, 1987), Ekholm et al (1988), Harms-Ringdahl (1986, 1988), Stapp (1982), Kelsey (1984), Kolehmainen, et al, (1989), Moroney et al (1988), Petrofsky and Phillips (1982), Phillips and Petrofsky (1983a, 1983b, 1986), Schuldt (1988), and Schuldt and Harms-Ringdahl (1987, 1988) and for the lumbar spine by Andersson et al (1988, 1980), Gracovetsky et al (1981), and McNeill et al (1980). Stresses on the spine increase if the trunk movements are subjected to high acceleration or deceleration (G-forces) as with aircraft pilots during flight (Andersen, 1988; Belytschko, 1978; Stapp, 1982; & Vanderbeek 1988), or with motorists during braking in a motor vehicle prior to or during a collision (McSwain, 1989; Stapp, 1982; Foust, et al, 1973; Mertz and Patrick, 1970). Excessive levels of stress on the head or neck are considered to be one of the major factors related to cervical dysfunction, injury, and myalgia (Harms-Ringdahl et al, 1986; Ekholm et al, 1988; Gracovetsky et al, 1981;

Schuldt, 1988). Weakness in certain neck or trunk muscles can predispose an individual to pain or injury (Andersson et al, 1988; Bean and Chaffin, 1988; Gracovetsky et al, 1981).

Statement of the Problem

Increased emphasis has been placed on quantifying the performance of neck and trunk muscles, especially within the framework of relating stress tolerance to external loads placed on the cervical spine (Harms-Ringdahl et al, 1986; Gracovetsky et al, 1981). The structural and mechanical integrity, stress tolerances, and injury mechanisms of the cervical spine have mainly been studied on cadavers or through biomechanical models. In-vivo cervical muscle activity has been measured using electromyography, and contraction forces have been estimated with mathematical models (Helleur et al, 1984, 1985; Moroney et al, 1988; Harms-Ringdahl & Schuldt, 1988). Traditional strength testing of the neck is performed manually (Daniels and Worthington, 1986; Kendall et al, 1971; Janda 1983). Manual strength testing is vulnerable to a subjective bias and intertester reliability has not been established (Mayhew & Rothstein, 1988). Normative values for static muscular strength of the cervical spine have not been confirmed.

The forces developed by isometric and isokinetic cervical muscle contractions have been measured in small population samples with conflicting results (Foust et al, 1973; Harms-Ringdahl & Schuldt, 1988; Petrofsky & Phillips, 1982; Moroney et al, 1988). Isometric force of sustained maximal and submaximal neck contractions was measured and compared by Petrofsky and Phillips (1982) using a group of four, adult, male subjects. Their results indicated that prolonged (> 60 seconds) maximal contractions produced muscle fatigue more quickly than did prolonged submaximal contractions. It has not been established as to whether there is a significant difference in the force developed by neck muscles between brief (< 3 second), single and repeated maximal isometric contractions.

In humans, muscle strength usually varies between the right and left sides within a subject for both the upper and lower extremities. This phenomenon of functional asymmetry has often been related to a unilateral strength or coordination dominance. Whether humans exhibit a similar asymmetry of lateral neck musculature strength that is related to upper extremity strength has not been documented.

In order for a clinician to assess whether or not a subject has the neck strength necessary to maintain the different head and neck postures required by work and leisure activities, the clinician must: 1) know the normal ranges

of cervical muscle contraction forces, 2) be aware of the presence or absence of functional strength asymmetry of the lateral neck muscles, 3) have knowledge of the normal ranges of force variability between muscle contractions, and 4) must know what forces the specific job requires. Therefore, a simple, reliable, method of testing cervical muscle contraction forces is needed.

Purpose

The primary aim of this study was 1) to establish normative values for the force developed isometrically by the neck muscles of the healthy adult male. Further questions to be investigated were 2) whether the isometric force developed by the neck muscles is related to anthropometric measurements (eg, height, weight, neck length, girth, or curvature), 3) whether grip strength and neck strength are correlated, 4) whether muscle force values of the cervical spine differ between single and repeated isometric contractions, and 5) whether a functional strength asymmetry exists between the lateral neck flexors. It is hoped that this information will improve the understanding of the normal cervical spine, and will help define the boundaries of strength below which injury might be potentiated.

Scope of the Study

The study involved the measurement of isometric neck muscle forces using a load cell. The sample population included 60 healthy, adult males, ages 18-35. Comparisons between the force generated in single and repeated isometric contractions of the tested cervical spinal muscles were made in order to determine the effects of fatigue or learning on muscle force. A correlation of hand dominance with ipsilateral and contralateral neck strength was performed. Trends in cervical muscle strength were observed. Anthropometric measurements of height, weight, neck length, girth, and curvature were taken for each test subject to determine if these measurements predicted neck strength.

Limitations of the Study

The sample population was not restricted by activity, rest or diet prior to participation in this study. Standardizing these variables may have produced different results.

Delimitations of the study

Delimitations were the large sample size, and the restriction of the population to healthy, adult, males within a specified age group.

Definitions

Force: An action which changes the state of rest or motion of a body to which it is applied. Newton's Second Law of Motion stated that force equals mass times acceleration. Newton's Third Law of Motion states that for every action there is an equal and opposite reaction. During an isometric muscle contraction, equal and opposite reactions have occurred until a state of equilibrium was achieved, and no acceleration or deceleration is occurring. Although the object (head on neck) did not move, energy was expended and force was generated. In this study, relative forces generated during isometric neck muscle contractions will be reported in units of force as measured in Newtons (1 Newton = 0.2248 lb).

Strength: In this study, the term "neck strength" will at times be used to signify the forces generated by the neck muscles during isometric contractions.

Load Cell: An electromechanical device which produces an electrical output signal that is linearly proportional to an applied force. The force can be either tensile or compressive. In this study, the load cell measured the tension placed on it by the subject's isometric muscle contractions.

Flexion: Movement of the head on the neck in a forward (ventral) bending direction occurring in the sagittal plane.

Extension: Movement of the head on the neck in a backward (dorsal) bending direction occurring in the sagittal plane.

Side Bending: Movement of the head on the neck in a lateral bending direction occurring in the frontal plane.

Isometric contraction: A partial or complete, static, muscle contraction, where both ends of the muscle are fixed and no appreciable movement occurs in the joint(s) involved.

Isometric flexion: Isometric contraction of the muscles of the neck which would produce flexion if motion were allowed.

Isometric extension: Isometric contraction of the muscles of the neck which would produce extension if motion were allowed.

Isometric side-bending: Isometric contraction of muscles of the neck which would produce bending to one side if motion were allowed.

Dominant hand: The hand that the subject uses for writing and fine motor activities.

Non-dominant hand: The hand that is less effective for fine motor activities.

CHAPTER 2

LITERATURE REVIEW

The elastic properties (load tolerances, stiffness, & deformation) of intervertebral discs and ligaments, and the precise attachments of cervical muscles have been measured on cadavers (Maiman et al, 1983). In-vivo muscle contraction forces have been estimated with biomechanical and mathematical models (Aspden, 1987; Moroney et al, 1988), or extrapolated from electromyography (EMG) (Fountain et al, 1966; De Freitas et al, 1980; Bull et al, 1984; Harms-Ringdahl et al, 1986; Basmajian, 1985; Phillips & Petrofsky, 1983).

Mathematical and biomechanical models of the forces on the spine

Bean and Chaffin (1988) developed a mathematical model to calculate the spinal compression and the intensity of muscle forces needed to resist external loads (222 N at 38 cm) applied to the lumbar spine. Calculated muscle forces were 695 N, 67 N, and 279 N for the erector spinae, latissimus, and abdominal obliques, respectively. Thoracic and lumbar vertebral equilibrium forces for an 11 year old, 499 N (112 lb.), male were calculated by Yettram and Jackman (1980) using a linear programming model. Muscle

Yettram and Jackman (1980) using a linear programming model. Muscle contraction forces of the multifidus at L-4 during forward flexion reached 900 N. In lateral flexion, multifidus forces at L-5 were 245 N. Intervertebral reaction forces (axial compression) below the level of T-12 during lateral flexion approached 1400 N.

Moroney et al (1988) constructed a biomechanical model of the neck using anthropometric measurements and surface myoelectric activity at the C-4 level to predict neck muscle contraction forces required during attempted cervical flexion, extension, lateral bending and twisting. Mean in-vivo neck muscle contraction forces were then estimated with comparisons to electromyographic activity (EMG). Calculated isometric neck muscle contraction forces for the left sternocleidomastoid muscle at C-4 were 140 N during attempted left side bending and 145 N during attempted flexion. Calculated forces for the left or right semispinalis capitis at C-4 were each 127 N (total 254 N) for attempted extension. Force estimates for the right sternocleidomastoid exceeded 170 N during attempted left rotation. Axial compression forces ranged from 122 N when relaxed to 1164 N during maximal attempted extension. Model validity was tested with 14 healthy, adult subjects who performed isometric tasks including exertive flexion, extension, bilateral side bending and twisting. Individual muscle activity was calculated from gross forces and the measured myoelectric activities for each muscle

group was linearly correlated with the force calculated for that muscle group. Correlation coefficients ranged from 0.29 to 0.85. These correlations were weaker than those found on the lumbar spine by Schultz (1981). Mean cervical spine strength for females tended to be 60-90% of mean cervical spine strength means for males, for all six exertive models. Validation of this model was limited by the small sample size tested (n=14).

Unusual load demands applied to the neck and trunk

High acceleration/deceleration forces increase the demands for strength and stability of the trunk and neck over and above the demand of normal loading. These severe loading stresses in aircraft pilots are often complicated by the weight of helmets or other headgear that the pilot might wear. Research has been directed toward finding the optimal "trade-off" between headgear needs and physiologic capabilities of the cervical spine.

Belytschko, et al (1978), used a three dimensional model of the human spine in relation to injury potentials resulting from arbitrary loads on the head-spine system. Their work focused on pilots wearing helmets which added an asymmetrical mass to the head. They evaluated pilot aircraft-ejection angles and stresses induced on the spine. The maximum acceleration of the head was 19.07 G over 60 ms (rapid onset) and 18.03 G over 72 ms (slow onset).

They calculated peak tensile forces in the cervical spine at 460 N during nonejection acceleration. Seat belt forces on the shoulders increased from 0 to 2270 N in 150 ms just prior to ejection from the aircraft.

Helleur, et al (1984), used a sagittal plane mathematical model of the cervical spine to simulate the neck's response to loads due to high acceleration. The variables they studied were: magnitude of acceleration, direction of the acceleration, and changes in the subject's posture. From their results, they estimated that the maximum acceleration which can be tolerated by the cervical muscles acting without the assistance of ligamentous support was 30 G for the neutral neck posture and 15 G for the fully flexed neck posture. When the load was simultaneously supported by the cervical muscles and ligaments, up to 40 G could be supported in the neutral neck posture.

Vanderbeek surveyed 437 fighter pilots exposed to sustained high G forces in regards to reported incidences of acute neck injury. Of the pilots surveyed, 50.6% reported experiencing an acute neck injury or episodes of neck pain within the previous three months of flying while 63.6 % reported experiencing either acute neck pain or injury within the past year. The findings indicated that individuals flying in aircraft that are capable of higher G forces had a high incidence of neck injuries.

Biomechanical analysis of compression loads on the cervical spine

Maiman et al (1983) used 13 unembalmed, male cadavers to study the crushing strength of the cervical vertebrae. Axial loads required to produce bony injury or ligamentous disruption ranged from 4500 N to 7439 N. Loads in flexion required to produce injury ranged from 645 N to 3000 N. Loads in extension required to produce injury ranged from 667.2 N to 4410 N. These loads are significantly greater than the in vivo loads calculated by Moroney et al (1988) using EMG activity of the cervical muscles during isometric muscle contractions when the head and neck are in the neutral position.

Radiologic studies

Radiology has been a mainstay of biomechanical research involving the cervical spine. It has been used to gather in-vivo segmental kinematic data of the spine (Breen, et al, 1988), to correlate injuries with pain assessments (Kelsey, et al, 1984), and to correlate the cross-sectional areas of the cervical spinal canal of non-injured controls with those of patients who had a traumatic injury to the spinal cord (Matsuura et al (1989). Through radiological research, it has been suggested that, given sufficient trauma, certain people may be predisposed to spinal cord injury or to neck injuries due to their lifestyle or occupations. To date, however, there has been not been any

documentation between cervical muscle strength and cervical spinal dysfunction as identified through radiologic methods, or between subjects predisposed to spinal cord or neck injury and cervical muscle strength.

Background on handgrip studies

The majority of handgrip force measurements have been recorded using the hand dynamometer. Similar force ranges for both dominant and non-dominant handgrip for the healthy adult males have been recorded by independent investigators (Young, et al, 1989; Mathiowetz, et al, 1985; Petersen, et al, 1988; Smith, et al, 1989). Ranges for dominant handgrips were 299.82 N to 531.81 N ($\bar{x}$ 429.47 N, sd 63.80 N), and for non-dominant handgrips were 271.31 N to 552.45 N ($\bar{x}$ 410.90 N, sd 71.66 N) for 34 healthy males, ages 18-67, as recorded by Young, et al (1989). These values are comparable to normative handgrip data recorded by Mathiowetz, et al (1985). Means for 83 adult males, ages 18-34, for the right hand were 538.21 N (sd 99.64 N), and for the left hand were 482.46 N (sd 88.52 N). Test positions were standardized according to recommendations by the American Society of Hand Therapists (Fess and Moran, 1981). Petrofsky and Phillips (1982) tested isometric strength and endurance for dominant handgrip and for dorsal, lateral, and ventral neck muscles in a small population sample (n=4), but did

not report on the presence or absence of a correlation between handgrip and isometric neck strength.

Isokinetic neck and trunk strength testing

Reports of isokinetic testing of the neck have been limited. The extent of cervical muscle recovery in athletes following acute neck injuries has been measured using a modified Cybex II by Gibbs and Ketterer (1980). Test results and normative data, to date, have not been published. Rogers (1984) reported using a modified Cybex II to evaluate the cervical spine musculature of high school football players. Claimed test-retest reliability was $r = 0.8845$. Test results and strength ratios were not reported.

The Cybex II has been used to evaluate the presence of functional trunk muscle asymmetries of trained and untrained athletes (Andersson, et al, 1988). Maximum voluntary isometric and isotonic strength relationships between trunk and hip muscles were measured. Their results indicated that trained athletes showed higher trunk muscle forces on the nondominant side as compared to the dominant side, demonstrating a functional asymmetry. For the untrained group, there were no significant differences in force generation between sides of the trunk.

Measurements of isometric trunk strength using load cells

McNeill et al (1980) measured maximum voluntary isometric trunk muscle contraction forces of both male and female healthy subjects and subjects with low back pain during attempted flexion, extension, and lateral bending from a controlled upright standing position. Their results indicated that patients with low back pain developed only 60% of the absolute trunk muscle contraction force of the corresponding healthy subjects. Patients with low back pain developed significantly less lumbar extension force than lumbar flexion force or lumbar lateral bending force while normal subjects produced higher muscle contraction forces in lumbar extension than in other directions. Force trends for normal subjects indicated greater strength in attempted extension ($\bar{x}$ 567 N), than flexion ($\bar{x}$ 403 N), than lateral bending ($\bar{x}$ 396 N), with no apparent strength asymmetry of the lateral trunk muscles. Force trends for patients with low back disorders, of less than six months duration, indicated greater strength in attempted flexion ($\bar{x}$ 348 N), than extension ($\bar{x}$ 279 N), than lateral bending ($\bar{x}$ 247 N). Force trends for patients with other types of lumbar dysfunction were consistent with the trends indicated above, although measured forces varied according to diagnosis.

Measurements of isometric neck strength derived from load cells and electromyography (EMG)

Foust, et al (1973) used EMG and load cells on a group of 180 male and female volunteers, ages 18-74, to measure cervical flexor and extensor muscle stretch reflexes and contraction forces. Average neck muscle reflex times for all subjects tested ranged from 56-92 ms for flexors and 54-87 ms for extensors. For males, ages 18-24, the reflex times for flexors was 65-74 ms, and for extensors it was 54-65 ms. Reflex times were longer after middle age. Their findings indicated that the cervical muscles generally were unable to react in time to moderate the hyperextension effects of an unexpected rear-end collision. Mean forces for neck extension for males ranged to 206 N (sd 46.3 N) and for females to 127 N (sd 28.7 N). Mean forces for neck flexion for males ranged to 162 N (sd 36.3 N) and for females to 91 N (sd 20.6 N).

Bjelle et al (1981), used isometric shoulder and handgrip muscle contraction measurements, EMG, and biomechanical analysis to evaluate acute shoulder-neck disorders among industrial workers. Subjects were divided into three categories: 20 patients with acute, non-traumatic, shoulder-neck pain, versus 26 normal controls that were matched to the patient group by age, sex, and place of work. The patients were divided into two groups: 13 without causative disease or spinal malformation, and 7 with probable

causative disease or spinal malformation. They reported that, despite similarities in anthropometric data between the patients and the controls, the measured isometric muscle strength was greater in the control group. Mean isometric muscle forces for shoulder elevation for controls was 776 N, for non-diseased patients forces were 712 N, and for diseased patients 563 N. Shoulder and neck injuries appeared to be due to many factors, including work load, load variation with time, muscle fatigue and duration of strain. This study, while verifying decreases in isometric upper extremity muscle forces in patients with dysfunctional shoulders and necks, involved testing and measurement of the upper extremity but not of the cervical spine. In this study, anthropometric data did not provide an effective means for predicting isometric muscle forces in either patient or control groups.

Helleur et al (1985), used EMG activity to calculate the cervical muscle forces of an unstated number of subjects performing maximal isometric extension from each of five different neck positions. Results ranged from 193.65-224.13 N in neutral, and 193.65-253.62 N in flexed positions, to 270.33 N from extended positions.

Cervical muscle forces developed during postures and motions necessary for factory work have been measured using EMG and strain gauges on 14 female volunteers (Schuldt, 1988). The effects of five sitting postures on neck

muscle strength of five sitting postures involving various degrees of cervical-thoracic flexion and extension were evaluated using surface electrodes placed over the upper trapezius, rhomboids, levator scapulae and sternocleidomastoid muscles. Results indicated that the position of the lower cervical spine, but not the upper cervical spine, influenced the levels of EMG activity recorded. During maximum voluntary isometric neck contractions, the percentage of Time-Averaged Myoelectric Potential (TAMP%), developed by the neck extensor muscles was higher (average range = 0-20 TAMP%) when the subjects were in flexed neck postures than when the subjects were in vertical (neutral) postures (average range = 0-10 TAMP%) (Schuldt 1988). These results demonstrate that neck position can effect the intensity of cervical muscle activity.

The use of the neutral neck position for testing isometric neck contractions and the importance of consistency in test position was described by Schuldt and Harms-Ringdahl, et al, (1988). Baseline EMG activity of the neck muscles was not evident when the subject is relaxed in sitting or standing with their head and neck in the neutral position or during free (gravity assisted) flexion, extension or side bending of the neck (Fountain et al, 1966; Vitti et al, 1973; Takebe et al, 1974; De Freitas & Vitti, 1980; Bull et al, 1984). The average weight of the adult, male, head was calculated to be 44.5 N (10 pounds) (Hubbard & McLeod, 1974 as cited by Hubbard, 1983) and is supported by

ligaments and bones in the neutral position during relaxed standing or sitting. EMG activity was elicited during forceful or resistive neck muscle contractions.

The influence of arm position on posterior neck muscle electrical activity during flexion and extension of the cervical spine was measured by Harms-Ringdahl & Ekholm (1988). They noted that elevation of the arms during head-neck movement increased the EMG activity in the three muscles tested (upper trapezius, splenius, rhomboids). In these studies, emphasis was on cervical extensor muscle activity. Muscle activity and contraction forces developed during side bending and flexion were not measured. An understanding of the muscular capabilities of the forward and lateral flexors of the neck is necessary for the accurate evaluation, treatment, and rehabilitation of cervical dysfunction.

The use of helmet dynamometers to measure the force generated by isometric cervical muscle contractions

Petrofsky and Phillips (1982) measured muscle fatigue of cervical and handgrip muscles on four, adult, male subjects using a helmet dynamometer and a handgrip dynamometer during prolonged maximal and submaximal contractions. Subjects were isometrically trained at various levels of submaximal cervical and hand muscle contractions. Their results indicated

that prolonged (> 60 seconds) maximal contractions produced muscle fatigue before prolonged submaximal contractions. Also, that muscle endurance of ventral flexion was less than that of dorsal or lateral flexion, while muscle strength was progressively greater for lateral, dorsal, and ventral flexion.

Cervical muscle loading and fatigue were investigated as related to asymmetric head weight. Six subjects wearing military aviation headgear, with asymmetric weights applied, were tested with an isometric head dynamometer for neck muscle fatigue as measured by isometric endurance time (Phillips and Petrofsky, 1983). Subjects were trained with brief (< 3 s) maximal isometric voluntary contractions, with an intercontraction interval of 3 minutes. Their purpose was to determine if some neck muscles were more tolerant of isometric exercise than others. Their results indicated that at low helmet weights (3 lb), physiologically optimal helmet loading was at a forward low or right-lateral-low center of gravity (CG). At intermediate helmet weights (5 lb), there was no apparent physiological optimal loading. At high helmet weights (9.0 lb), the physiologically optimal helmet loading was on the back of the helmet. Cervical muscle fatigue (as measured by endurance to isometric exercise) was related to both the position of the load and the intensity of the load.

EMG activity of cervical muscles during brief (< 3s) and prolonged (sustained until fatigue) contractions of five adult, male subjects was studied by Phillips & Petrofsky (1983). Surface EMG activity was measured over the right sternocleidomastoid and trapezius/splenius muscles. Variations in neck EMG activity was monitored while the subject performed isometric right and left lateral neck contractions with either no head loading or while the subjects wore a helmet dynamometer and night vision goggles on their head. Results showed that when the load on the head and neck was increased during prolonged contractions, a 78% average increase in the root mean square amplitude of the EMG occurred, and a 27% average decrease in the center frequency of the EMG. These findings were consistent with EMG changes associated with isometric muscle fatigue.

SUMMARY

The load tolerances of discs and ligaments, and precise muscle attachments of the cervical spine have been measured on cadavers. In-vivo muscle contraction forces have been estimated with biomechanical and mathematical models or extrapolated from EMG. Theoretical models are useful for providing ways to solve biomechanical problems involving stress tolerances of the spine and to predict loading or acceleration forces acting on the spine. Many of these models need to be validated by comparing model predictions with human performance data.

While radiological techniques can offer valuable insight into spinal mechanics and susceptibility to injury, they are not yet feasible for estimating or measuring spinal torque or muscle contraction forces.

Test results for handgrip forces have been recorded using the hand dynamometer. Test positions have been standardized according to recommendations by the American Society of Hand Therapists. Normative data for handgrip forces using the hand dynamometer have been established.

Studies involving isokinetic testing of the cervical spine have not been adequately reported to provide useful data. The use of load cells and helmet

dynamometers for measuring the contractile forces of lateral neck muscles have been limited to small populations. The correlation between cervical posture and the myoelectrical activity of neck extensor muscles has been well documented.

Normative values for isometric cervical muscle contraction forces have been recorded for side bending in small (n=4) subject populations. Values for muscles contraction forces developed during cervical flexion and extension have been recorded for larger populations with conflicting results. The correlation of hand dominance with isometric neck force, the prediction of neck forces from anthropomorphic measures, or the effects of brief single versus repeated isometric contractions on estimates of cervical muscle force generation has not been documented. There is a need to collect this data because if a clinician knows what muscle forces are necessary to perform work or leisure activities, it can help the clinician assess whether a subject has the neck muscle forces necessary to perform their work or leisure activities.

CHAPTER 3

METHODS

SELECTION OF THE SAMPLE

Subjects 60 healthy male volunteers, ages 18-35 years, were used for the muscle strength tests. The subjects were not chosen from any specific athletic group. Volunteers were recruited from the student body on campus by word of mouth and by advertisements posted on campus. Subjects did not receive monetary compensation for participation in the study. Subjects with known cardiovascular, neuromuscular, or musculoskeletal problems or neck pain which occurred within the last year, and lasted longer than 1 week were excluded from the study. All subjects read and signed an informed consent form (see Appendix A) that was approved by the University of Kentucky Institutional Review Board.

MEASUREMENT DEVICES

Data collection equipment included a stabilization system (described below), a head harness strap, a load cell with signal amplifier, a flexible

cervical ruler, tape measure, scale for body weight and height, a micro computer, and a hand dynamometer.

COLLECTION OF DATA

Anthropometric measurements

Age and hand dominance were collected per subject report. Subject weight, height, neck length, girth, and cervical spinal curvature were measured while the subject was standing. Neck circumference was measured at the horizontal level of the spinous process of the C-7 vertebrae. Neck length and curvature were measured from the inion to C-7 according to Rheault (1989) using a flexible ruler[1].

Measurement of handgrip strength

Hand grip was measured using a spring dynamometer (Lafayette[2]). The dynamometer was calibrated prior to the study and again following the completion of data collection from the sample population. The dynamometer

[1] Spinocurve, Box 869, Wayne, Pennsylvania, 19087

[2] Lafayette Instrument Co., 3700 Sagamore Parkway North
P.O. Box 5729, Lafayette, Indiana, 47903

demonstrated linear accuracy from 0-734 N (0-165 lbs.). For testing of grip strength, subjects were seated with their humerus adducted against the mid-axillary line of the thorax and in neutral rotation. The elbow was flexed to 90 degrees and the forearm and wrist were in neutral rotation in accordance with the recommendations by the American Society of Hand Therapists (1985) and Young (1989). The dynamometer was adjusted for comfortable fit to the hand of each subject prior to testing. Each subject was instructed to squeeze the dynamometer handle as hard as they could for three seconds. Three trials were performed on each hand with a 60 seconds rest between each trial. Instructions were standardized to familiarize the subjects to the grip test device and procedure (Appendix B).

Measurement of isometric neck strength

Isometric neck strength was tested while the subjects were seated (Figure 1). A wheel mounted, hydraulic chair[3] was used. For data collection, the detachable head rest was removed. Subjects were stabilized to the backrest of the chair by three restraining straps to inhibit movement of the trunk during exertions. One strap was placed across the hips, the other two straps crossed the trunk diagonally from each shoulder to the opposite hip.

---

[3] Biodex Corporation, P.O. Drawer S., Shirley, New York, 11967

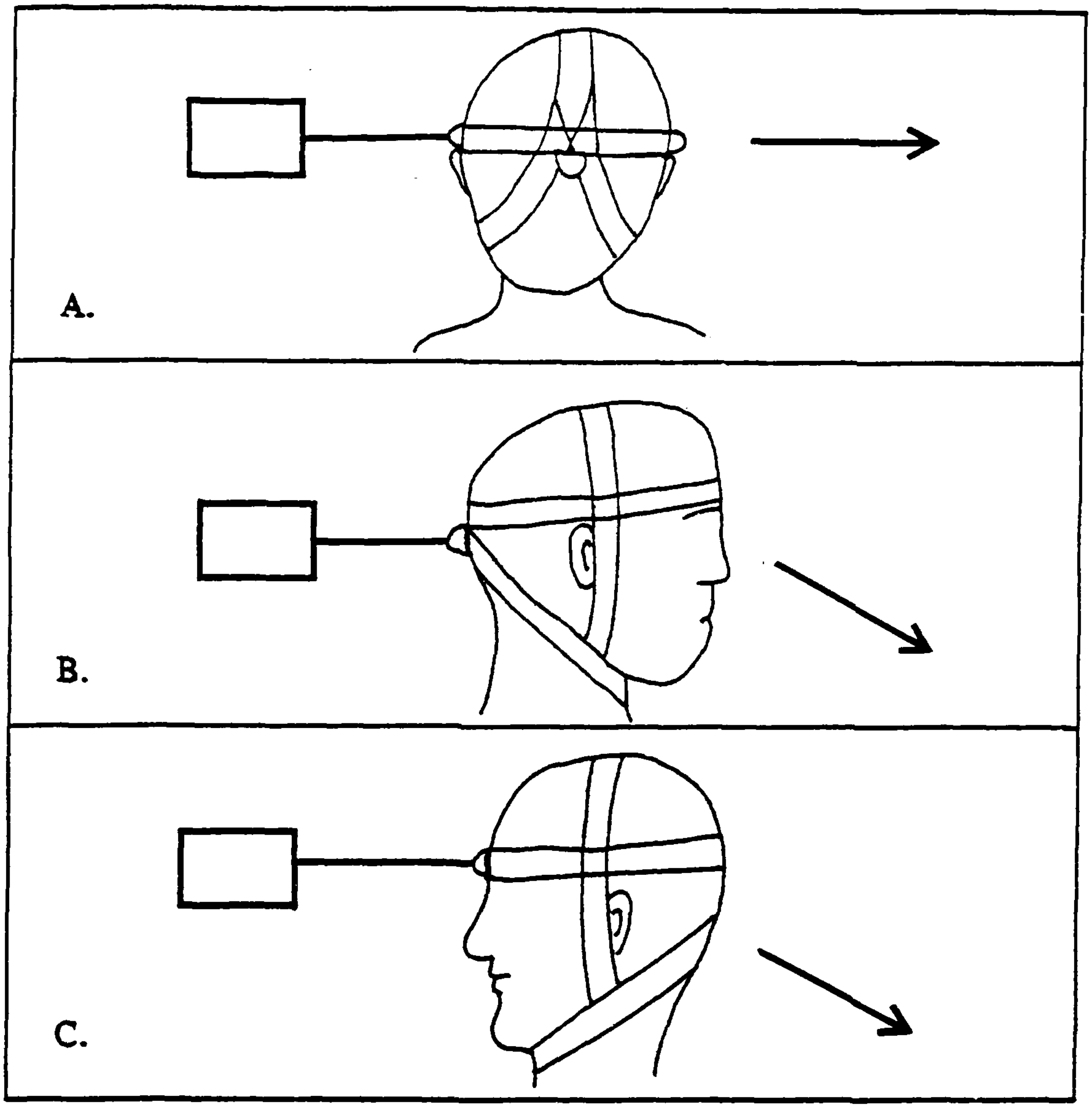

Figure 1: Position of subject prior to measurement of isometric neck contraction forces: A. Side bending B. Flexion C. Extension

The subjects were instructed to cross their arms over their chest to eliminate substitution of upper extremity musculature. Subjects were instructed to relax their legs and not brace their feet against any part of the chair during the test contractions.

Subjects were fitted with an adjustable head harness[4] that was modified with additional velcro and a D-ring belt strap to eliminate movement of the head within the harness during the contraction. The head harness was fitted with D-rings placed at the horizontal level of the supraorbital ridge anteriorly and laterally, and at the level of the occiput posteriorly. The rings were used to attach the head harness to the load cell by way of a metal chain. The length of the chain was adjustable to allow individual adjustment for each subject. The position of the strap was individually standardized for each subject. The subject's head was pre-positioned in a plane horizontal to the direction of the neck muscle contraction as in Figure 1. The chair height was adjusted in relation to the subject's sitting height. The chain length was adjusted until the slack was picked up in relation to the head harness and the wall mounted load cell. The final subject position for testing was: seated in the chair, trunk stabilization straps in place, 80 degrees of hip flexion, trunk 10 degrees posteriorly inclined from vertical, lower legs unsupported, arms crossed, head and neck in neutral position, head harness in place, and slack in the chain taken up.

Subjects were instructed to generate maximal isometric force for three seconds by pressing their head against the head harne 's strap. The

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[4] Medi-cordz, NZ MFG INC, 15138 65th Ave. S, Suite 107
Seattle, Washington, 98188

subject's isometric contraction placed tension on the load cell via tension on the chain.

The force generated by the contraction was detected by the load cell[5] which was interfaced with a signal amplifier[6], low pass filtered at 40 Hz, and then connected to an Analog to Digital interface board[7]. Data storage was accomplished with a microcomputer running ASYST[8], sampling at 2000 Hz. The digital signal was converted to units of force through the use of calibration values. The calibration of the load cell was performed daily prior to data collection and checked before and after each subject. The system was re-calibrated if measured load cell drift was greater than +/- 10 N (2.25 lb).

Subjects generated force in four directions: right and left lateral flexion, forward flexion, and extension, by exerting a maximum isometric contraction for three seconds while in each position. Three successive trials in each

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[5] Model SM 500, serial # A53947, Interface Inc., Scottsdale, Arizona.

[6] Therapeutics Unlimited GCS 67, Main Frame with force transducer module, FPM 544, Iowa City, Iowa

[7] DT (Data Translations) DT 2821 SE, MacMillian Software Company, 866 Third Ave, New York, New York, 10022

[8] ASYST, version 2.01, MacMillian Software Company, 866 Third Ave, New York, New York, 10022

direction were recorded, with 60 seconds rest between trials. Data were collected for the final two seconds of each three second contraction, allowing subjects time to achieve their best static contraction and to eliminate any motion artifacts that might have occurred as the contraction was initiated. The order of tested directions was randomized. The chair was randomly turned either 90 or 180 degrees between sets of trials, then the seat height was individually adjusted to achieve the correct position for the ensuing trial. Test position for the head and neck was always the subject's neutral position. The neutral position was visually confirmed by the experimenter immediately before each data collection when the subject was relaxed in the test position. Standardized instructions were given to each subject to familiarize them with the test for each of the four test positions (Appendix 3). Subjects did not warmup, but were allowed to exert a single submaximal isometric contraction prior to testing to familiarize themselves with the apparatus and to demonstrate understanding of the indicated test contraction. Subjects were asked not to exert force beyond a level that was pain free and were instructed prior to data collection that should neck pain be experienced that they were to inform the examiner and should discontinue the contraction at that time.

Instrument reliability

Prior to implementation of data collection, three hand dynamometers were tested using known weights, and the most reliable of the three, the Lafayette, was chosen for the handgrip testing in this study. The Lafayette hand dynamometer demonstrated linear accuracy from 0-685 N (154 lbs.) which was beyond the ranges reported by independent investigators (Mathiowetz, et al, 1985; Petersen, et al, 1988; Smith, et al, 1989; Young, et al, 1989).

Reliability of the load cell was tested with known weights. The load cell was rated by the manufacturer from 0 to 2224 N (0 to 500 pounds). Accuracy of the load cell was rated at 0.03% Static Error Band. Load cell reliability and calibration were tested in two ways. First, with the load cell rigidly mounted to a wall, horizontal tension was exerted on the cell with known weights using a pulley mechanism. The horizontal tension was congruent with the line of pull that the cell would be receiving during actual data collection. Second, the load cell was tested in a vertical mounting with the same weights hung directly from the load cell. There was no significant difference measured between the vertical and horizontal methods of calibration. Therefore, only the horizontal calibration method was used in the remainder of the study as seen in Figure 2. The calibration pulley was removed prior to data collection without touching the load cell. Output from

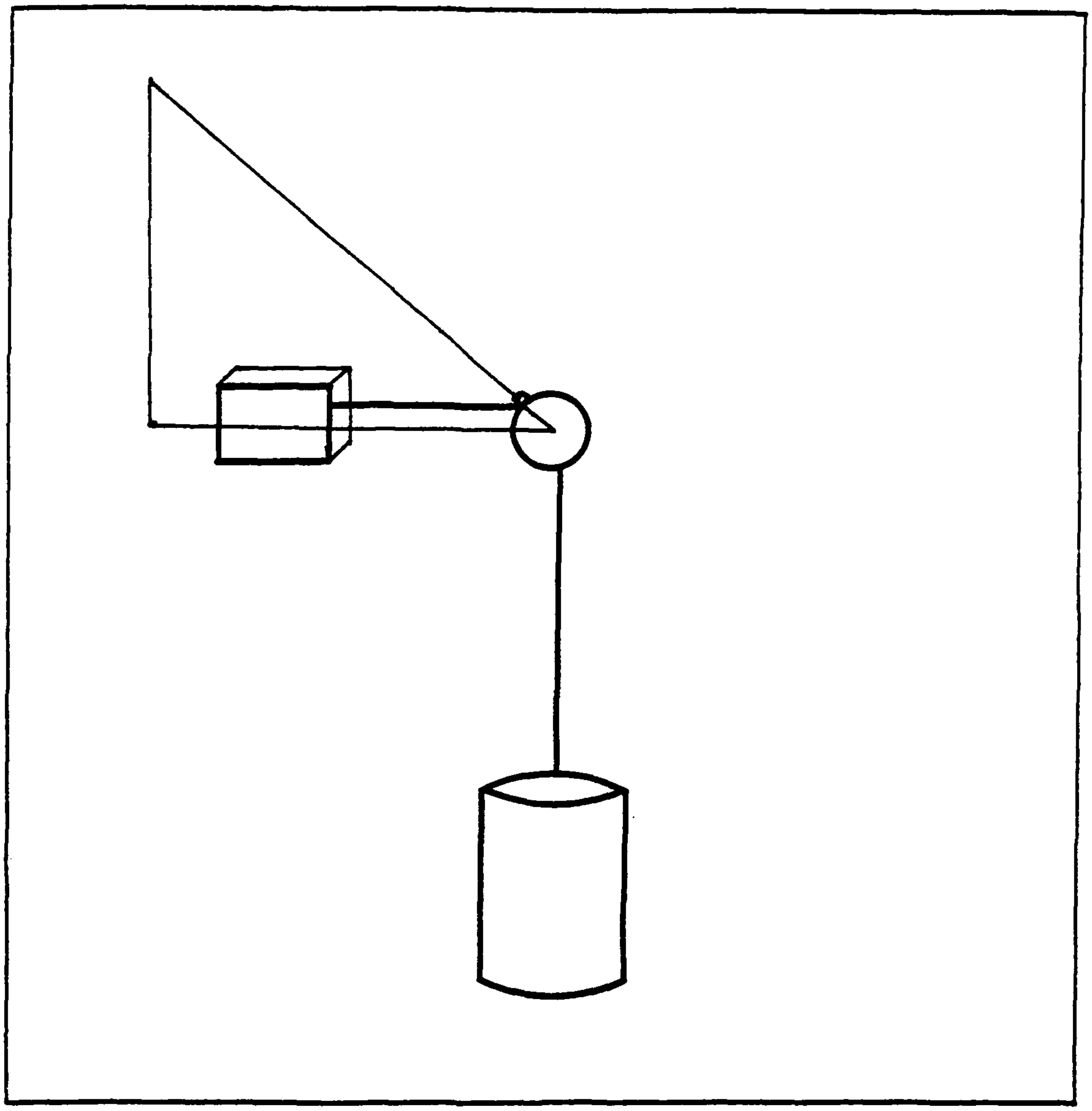


Figure 2: Wall mounting for load cell calibration in the horizontal position. The pulley and weights were removed prior to data collection.

the load cell was checked prior to data collection and throughout the experiment using an ohmmeter and an oscilloscope and was found to be accurate. Accuracy of the load cell demonstrated linear reliability from

0-482 N (108.5 lbs) which was beyond the anticipated range of cervical muscle forces.

Individual subject body weight was measured using a household balance scale with digital display (smallest division was 0.5 lbs or 2.224 N), The scale was calibrated with known weights and demonstrated linear accuracy from 0 to 1000 N (0-225 lbs.).

TEST-RETEST RELIABILITY

Six subjects (10%) were randomly selected to return at a later date for retesting to assess test reliability. The average time between the tests was 30 days. Their initial results were evaluated with both the entire population sample (n=60), and the test-retest sub-population (n=6).

DATA ANALYSIS

Calculation of neck forces

Raw data were converted from analog to digital signal, analyzed using a customized data analysis program written in ASYST 2.01, and recorded on individual Subject Information Sheets (see Appendix D). Each trial was viewed for the entire two-second collection window, and the highest 0.5 second of the force-vs-time curve containing the consistently highest force was used for analysis (see Appendix E). The mean force for the 0.5 second epoch was calculated for each subject trial. Instantaneous peak forces were also calculated. The greatest force that was maintained for a minimum 0.05 seconds was recorded and termed the "instantaneous peak force". Higher forces that were generated for less than 0.05 seconds were ignored due to the possible presence of signal artifact. Average and peak forces for the three trials for each of the four directions were averaged separately for each subject. Intra-individual and group means were calculated for single trials and the combined sum of the three trials.

Statistical analysis

Statistical comparisons were made using Pearson's Interclass Correlation Coefficient (ICC), t-tests and separate multifactorial ANOVAs. Using the Pearson ICC, a perfect correlation is 1.00, a "strong" correlation is > 0.85, a "moderate" correlation is 0.65 to 0.85, a "weak" correlation is < 0.65, and no correlation is 0.00. The level of significance was set at $p < 0.05$. The correlation of hand dominance and isometric neck strength, and the use of neck length, girth, and curvature measurements as strength predictors were evaluated using the same criteria.

CHAPTER 4

RESULTS AND DISCUSSION

Results

Of the sixty subjects who volunteered for this study, all were able to complete to entire test sequence without incident or complaint of discomfort during the testing. Three subjects reported having transient neck muscle soreness the day following the test, which resolved within a day by subject report.

Anthropometric measures

Subject characteristics are summarized in Table I. The test-retest sub-population were within 0.5 sd of the test population means for anthropometric characteristics. There was no significant difference between the two populations.

Correlations between anthropometric measurements and neck strength, as seen in Table II, were weak or not evident with the exception of neck girth

Table I: Summary of Anthropometric Measures Describing the Population Sample (n=60) and the Test-Retest Sub-population Sample (n=6).

	Population Sample (n=60)		Test-Retest Sub-population (n=6)	
	Mean	sd	Mean	sd
Age (yrs)	22.78	(4.28)	24.00	(1.53)
Height (cm)	176.43	(7.16)	179.39	(5.63)
Weight (kg)	76.94	(9.75)	78.77	(2.72)
Neck Length (cm)	15.01	(1.40)	14.81	(1.14)
Neck Girth (cm)	42.84	(2.74)	43.23	(1.11)
Curvature (deg)	62.45	(11.43)	56.73	(8.64)

Table II: Correlations Between Anthropometric Measurements and Isometric Neck Strength (n=60).

		HEIGHT	WEIGHT	LENGTH	GIRTH	CURVE
Right	r=	-0.128	0.077	-0.314	0.310	-0.074
	p=	0.328	0.561	0.015*	0.016*	0.574
Left	r=	-0.026	0.124	-0.152	0.339	-0.158
	p=	0.842	0.344	0.246	0.008*	0.228
Flexion	r=	0.020	0.233	-0.242	0.336	-0.074
	p=	0.877	0.073	0.063	0.009*	0.575
Extension	r=	0.043	0.258	0.010	0.345	-0.194
	p=	0.746	0.046*	0.938	0.007*	0.137

* = statistically significant correlation
r = pearson correlation coefficient

(r = 0.31-0.35). There was a weak negative correlation between neck length and right lateral neck strength (r = -0.31). The p values for these relationships were significant at 0.01. There was a weak correlation between body weight and neck extension strength (r = 0.26) with a significant p value of 0.046.

Hand grip strength

The combined means for the three trials of hand grip strength are summarized in Table III. Of the 60 subjects in the population sample, 54 (90%) were right hand dominant. In the randomly selected retest sample, all six subjects were right hand dominant. Mean handgrip strengths for the test-retest sub-population were within + 1 sd of the mean for the population sample, and within + 0.5 sd of each other for either hand, as seen in Figure 3. In Figure 4, it can be noted that there was no effect due to test order for the combined means of grip strength for either hand. The results of a repeated measures ANOVA were PR > F = 0.88 for the dominant hand, and PR > F = 0.33 for the non-dominant hand. Table IV summarizes test reliability for three trials of handgrip testing. For the dominant handgrip, test reliability was 85.5%, and for the non-dominant handgrip reliability was 92.3%.

Table III: Summary of Combined Means of Handgrip Strength (Newtons) for the Population Sample (n=60) and for the Test-Retest Sub-population (n=6).

	Mean	sd	Range
Entire Population (n=60)			
Dominant	489.19	60.31	379.15--621.03
Non-dominant	456.23	56.53	344.85--583.46
First Test for Subpopulation (n=6)			
Dominant	534.52	29.98	475.58--563.83
Non-dominant	473.13	34.03	428.21--514.81
Re-test for Subpopulation (n=6)			
Dominant	519.97	42.30	452.72--589.98
Non-dominant	487.86	25.71	447.83--521.35

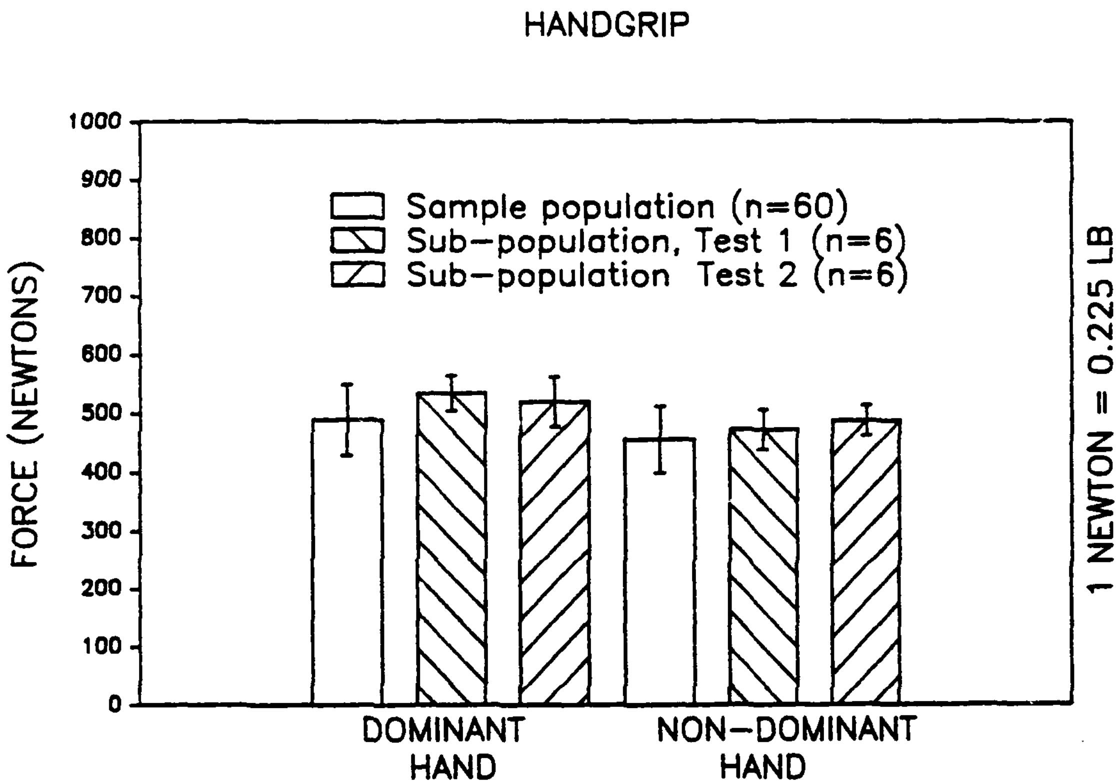


Figure 3: A Comparison of Handgrip Strength Between the Sample Population (n=60) and Tests I and II of the Sample Sub-population (n=6).

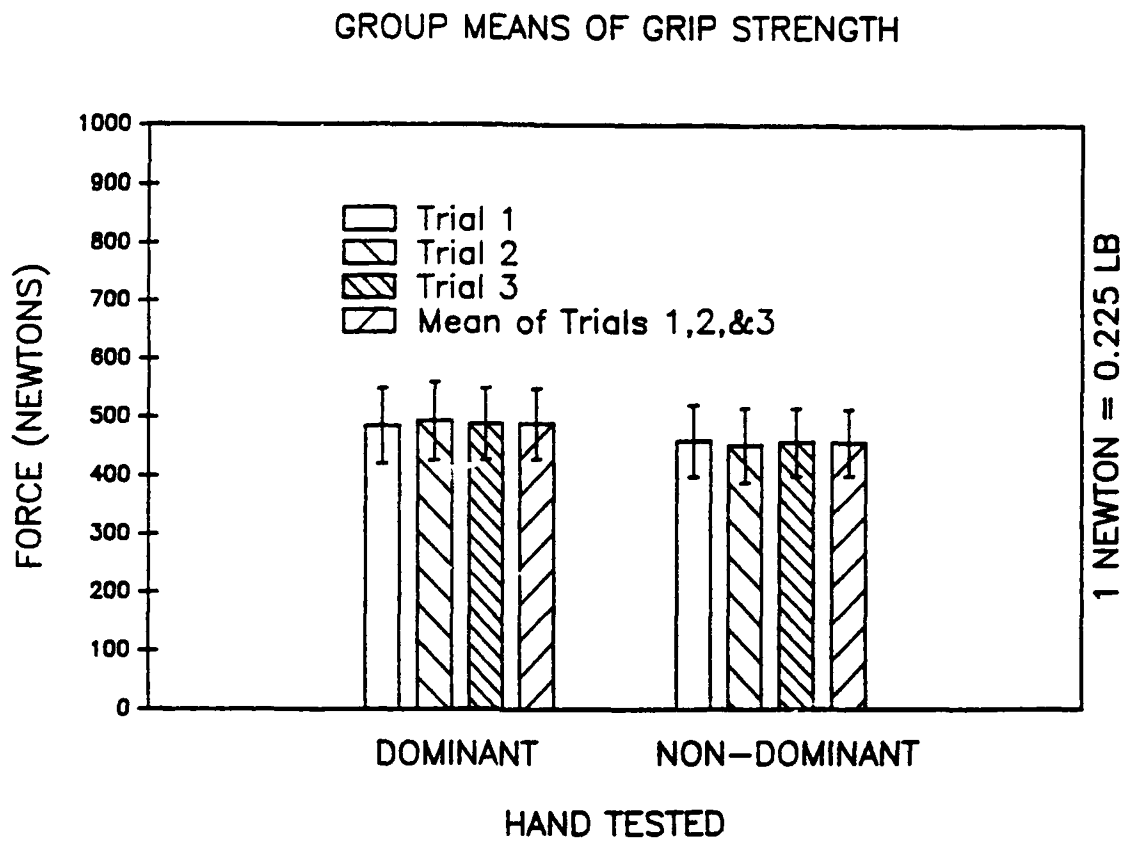


Figure 4: A Comparison of Handgrip Strength Between the Three Test Trials for the Sample Population (n=60). Bars indicate the combined group mean for the trial. Error bars indicate ± 1 sd.

Table IV: Handgrip Test Reliability

Variable	Variance Components: Within Subject	Variance Components: Between Subject	Inter-Class Corr. Coeff.	Observed Reliability Of $\bar{X}$ of 3 Trials
Dominant	89.32	174.33	0.66	85.5%
Non-dominant	37.70	149.01	0.80	92.3%

Isometric neck muscle contraction forces

Mean isometric forces generated by the neck muscle contractions during flexion, extension, and side bending to either side were calculated for the 0.5 second epoch that demonstrated the greatest force magnitude during the two second data collection window. These are summarized in Table V for the sample population. Table VI summarizes the comparable forces for the test-retest subpopulation. It can be noted that for all three groups, average isometric neck strength was greater in extension, than flexion, than side bending to either side. This trend is further evident in Figure 5. Average isometric forces for both sides of the neck were similar (< 0.5% difference between the two sides).

Figure 6 illustrates that test order between trials for neck strength testing was significant (PR > F = 0.0001) for all directions tested. Forces produced by the isometric neck contractions increased from the first to the last trial, indicating the presence of a learning trend. This learning trend is most noted in side bending and forward flexion.

Table V: Average Isometric Neck Forces (Newtons) for the Sample Population, (n=60).

	$\bar{x}$	sd	Range
Right Side Bend	152.70	36.47	84.65--243.71
Left Side Bend	158.66	38.96	94.87--262.70
Flexion	202.25	48.57	114.27--340.54
Extension	236.06	48.44	132.33--391.42

Table VI: Average Isometric Neck Forces (Newtons) for Tests I and II for the Sample Sub-population (n=6).

	$\bar{x}$	sd	Range
Test I:			
Right Side Bend	164.62	43.37	92.61--207.59
Left Side Bend	165.64	45.10	93.93--224.76
Flexion	213.19	49.86	114.27--251.58
Extension	245.71	46.93	164.18--288.01
Test II:			
Right Side Bend	175.87	52.31	79.04--231.61
Left Side Bend	171.29	39.14	97.50--204.74
Flexion	213.95	56.09	103.24--252.31
Extension	244.05	64.58	116.27--295.17

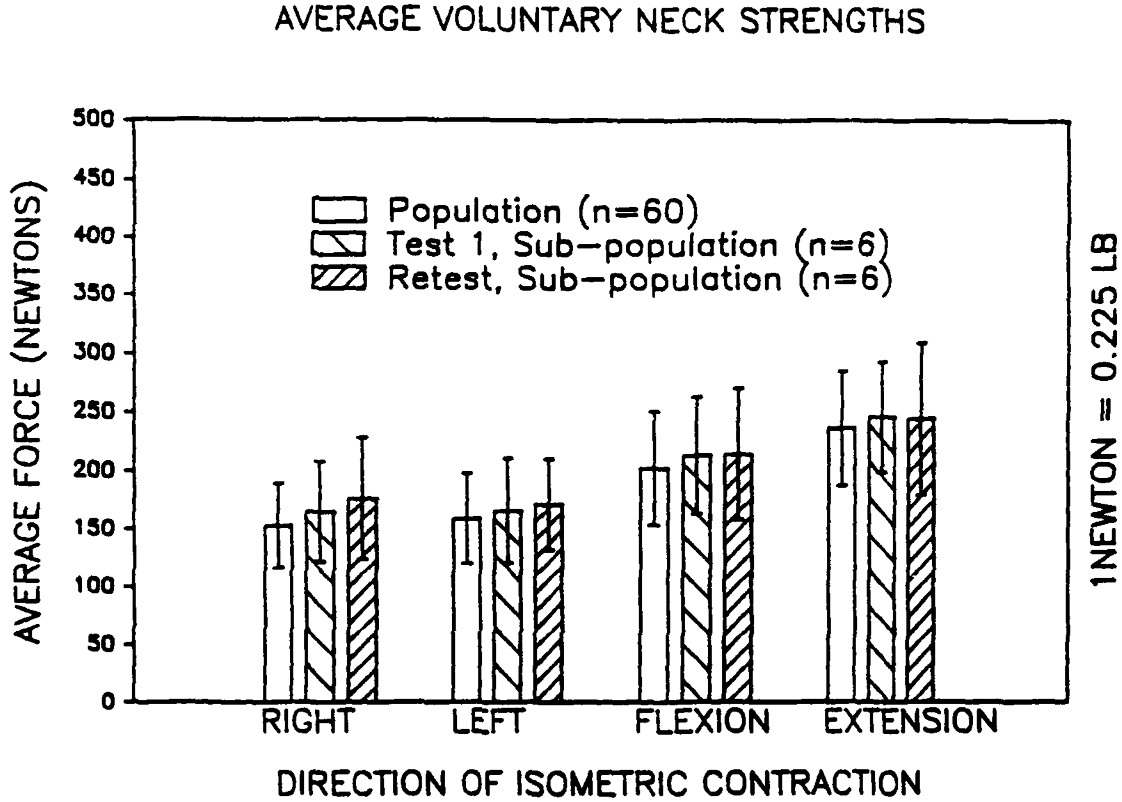


Figure 5: A Comparison of Neck Strength Between the Sample Population (n=60) and Tests I & II of the Sub-population (n=6). Bars indicate the combined mean. Error bars indicate $\pm$ 1 sd.

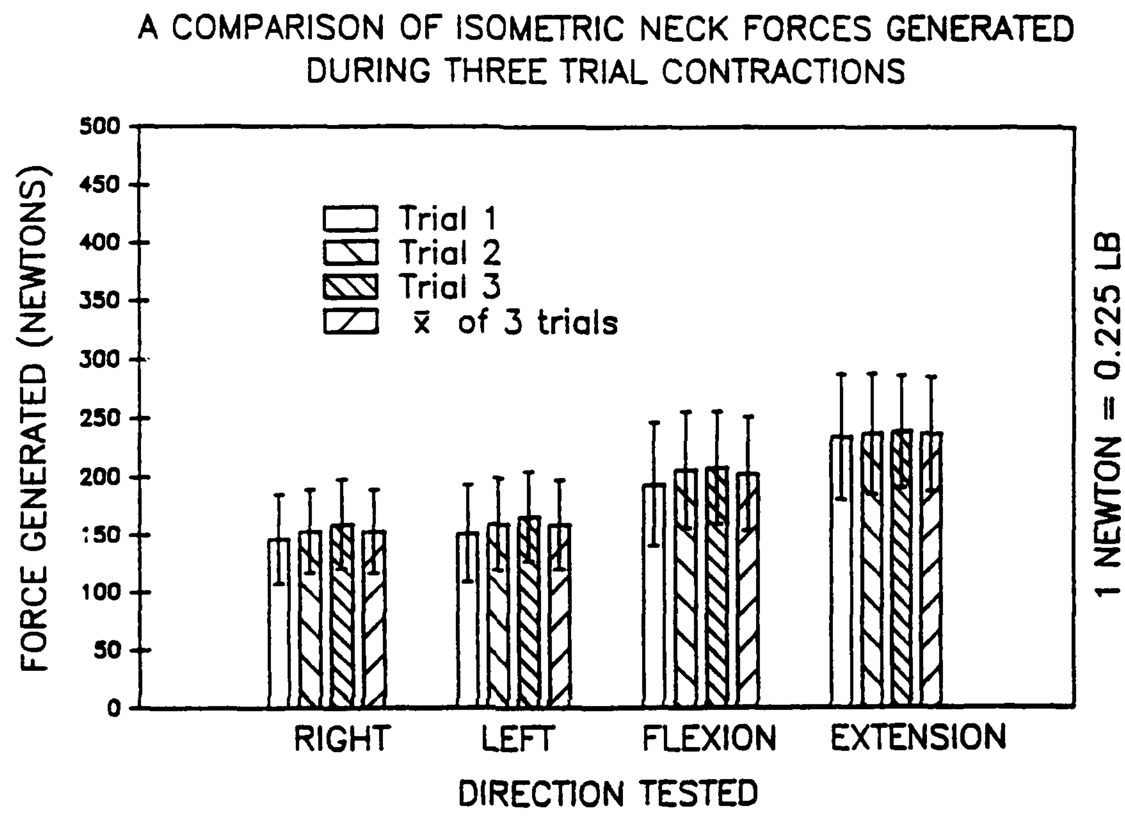


Figure 6: A Comparison of Isometric Neck Strength Between the Three Test Trials for the Sample Population (n=60). Bars indicate the combined group mean for each trial. Error bars indicate ± 1 sd.

Instantaneous peak forces for isometric neck muscle contractions which lasted at least 0.05 seconds during the 0.5 second epoch are summarized in Table VII for the subject population, and in Table VIII for the test-retest sub-population. Instantaneous peak forces were not significantly greater than the calculated mean forces. For the subject population (n=60), mean forces were 96.79% of the instantaneous peaks for right side bending, 97.56% for left side bending, 98.04% for flexion, and 99.01% for extension. Comparisons for the test-retest sub-population indicated the same close relationship between instantaneous peak forces and calculated mean forces.

The results of paired t-tests to compare the differences between the combined means of three trials of isometric neck testing during tests 1 and 2 for the sub-population are given in Table IX. These results indicate that there were no consistent differences in the forces generated by isometric neck muscle contractions between testing sessions for the test-retest sub-population. Subjects did not consistently produce more or less force on the first test session as compared to the second test session.

Table VII: Instantaneous Peak Isometric Neck Forces (Newtons) for the Sample Population (n=60).

	$\bar{x}$	sd	Range
Right Side Bend	157.77	37.32	84.65--240.06
Left Side Bend	162.62	39.59	94.20--249.62
Flexion	206.30	49.06	116.67--343.30
Extension	238.41	52.13	106.00--393.29

Table VIII: Instantaneous Peak Isometric Neck Forces (Newtons) for Test I & II for the Sample Sub-population (n=6).

	$\bar{x}$	sd	Range
<u>Test I:</u>			
Right Side Bend	168.67	44.79	95.05--214.44
Left Side Bend	153.19	46.66	96.74--227.65
Flexion	216.80	50.66	116.67--256.47
Extension	254.74	49.55	165.82--304.24
<u>Test II:</u>			
Right Side Bend	179.25	44.79	80.64--235.39
Left Side Bend	173.96	40.21	99.77--209.19
Flexion	213.45	56.62	104.52--255.67
Extension	246.15	65.30	117.29--298.99

Table IX: Results of Paired t-tests Comparing the Differences Between the Means of the Strength Variables Measured in Tests I & II for the Sample Sub-Population (n=6).

Strength Variable	Difference Between the Test $\bar{X}$ s	SEM	t	PR > (t)
Dominant Grip	14.54	24.15	0.60	0.5738
Non-dominant Grip	-14.72	20.10	-0.73	0.4975
Right Side Bend	-11.25	7.29	-1.54	0.1833
Left Side Bend	- 5.65	10.68	-0.53	0.6173
Flexion	- 0.76	5.47	-0.14	0.8946
Extension	1.60	14.32	0.11	0.9144

Observed test reliability for isometric neck testing is presented in Table X. For three trials, observed test reliability was strong for all directions tested (ICC. = 0.88-0.90).

As indicated in Table XI, there was no correlation evident between grip strength on either side and lateral neck strength.

Table X: Isometric Neck Strength Test Reliability

Variable	Variance Components: Within Subject	Variance Components: Between Subject	Inter Class Corr. Coeff.	Observed Reliability Of $\bar{X}$ of 3 Trials
Right Side Bend	9.06	64.17	0.88	95.2%
Left Side Bend	9.09	73.73	0.89	96.0%
Flexion	12.68	105.03	0.90	96.0%
Extension	17.26	112.74	0.87	94.9%

Table XI: Correlations Between Hand Grip Strength and Ipsilateral and Contralateral Neck Strength (n=60).

Correlated:	Pearson r	p
Dominant grip vs Ipsilateral neck strength	0.11	0.39
Nondominant grip vs Ipsilateral neck strength	0.24	0.06

Correlated:	t	PR>[t]
Dominant vs nondominant grip	5.19	0.0001*
Right vs left neck strength	-0.89	0.3756

(*) Indicates significant findings

Discussion

Anthropometric Measurements

The lack of correlation in this study between anthropometric characteristics and measured isometric neck forces suggests that these characteristics would not be useful as accurate predictors of normal neck strength for the healthy, adult male. This corresponds with the work of Bjelle, et al (1981), who reported that anthropometric measurements were not useful as predictors of voluntary upper extremity muscle contraction forces in patient or normal populations.

Subjects in this study were comparable to those tested by Foust et al (1973), Helleur et al (1983), and Petrofsky and Phillips (1982) in regards to physical height, weight, and age. Neck girths were taken at different levels in the different studies and were therefore not comparable. Petrofsky and Phillips (1982) did not report the level of the neck that they measured to determine neck girth, and Moroney (1988) calculated anterior-posterior and lateral neck diameters at the level of the C-4 vertebrae. Measurements of neck girth were not reported in the remainder of the studies cited here. The weak correlation noted between neck girth at the level the of C-7 vertebrae (Table II) was probably influenced by the greater bulk of the trapezius at this

level as compared to higher on the neck, and measurement at the C-7 level was awkward.

Neck length and spinal curvative measurements as strength predictors for isometric cervical strength have not been reported in other studies to date. There have been no reports to date of normative ranges of cervical curvature in any population sample. These measurements of neck length, girth, and curvature are useful as a basis for normative ranges for the population tested, but do not correlate well with neck strength measures.

Handgrip strength

Of the three dynamometers tested for reliability in the pilot study, the Lafayette was the most reliable when measured against known weights and was thus chosen for the study. Subjective comments indicated that it was not a comfortable instrument to use and many subjects did not feel that they could exert as much pressure as they had wanted, which might have influenced the results. The measured handgrip forces, however, were very comparable to those published by Young (1989), Mathiowetz (1985), Petersen (1988) and Smith (1989) for comparative subject populations using the Jamar hydraulic dynamometer.

Grip differences between dominant and non-dominant hands while demonstrating a functional asymmetry (Table III), were within 10% of one another. This result is consistent with normal ranges established by Bechtol in 1954, as cited by Petersen, et al (1989), and for right hand dominant subjects (Petersen, et al, 1989). Hand grips for dominant and non dominant hands for left hand dominant subjects in the present experiment were within 8% of each other. This exceeds the ranges of -0.08% recorded by Petersen, et al (1989) for left hand dominant subjects. However, the population sample of left hand dominant subjects was small in this study, thus it would be difficult to extrapolate these results further.

Test reliability for within subject variation for three trials of handgrip testing (Table IV) was lower than the 90% level desired for the dominant hand, and 92% for the non-dominant side. Comfort of the dynamometer may be one variance factor. Increasing the number of repetitions beyond three trials may have improved the reliability of the results.

Neck strength

The concept of whether a maximum voluntary isometric muscle contraction (MVIC) is an accurate indicator of the maximum force that a muscle is capable of producing is debatable. In measures of trunk strength,

Gracovetsky (1981) estimated that only 67% (2/3) of the ultimate strength of the muscles are recruited in a maximum voluntary contraction. Chaffin & Baker (1970) estimated that the maximum voluntary contraction of trunk muscles approaches 80-90% of the ultimate contraction that the muscle is capable of producing. The lower forces of MVIC leave a reserve for involuntary or subconscious displays of abnormal strength, and acts as a protective mechanism for the spine. The forces of voluntary neck muscle contractions measured in this study are representative of normal strength ranges rather than ultimate strength ranges for the muscle forces tested. As there were no significant differences between mean voluntary contractions and instantaneous peaks, most of the discussion herein will center on mean neck contraction forces measured.

Mean neck contraction forces measured were within the anticipated limits estimated by Moroney (1988), and below the levels of contraction forces that could cause injury to the spine or vertebrae. Mean forces for neck flexion and extension measured in the present study exceeded the force means and ranges for neck flexion and extension recorded by Foust (1973), and Petrofsky & Phillips (1982). Measured neck extension forces in the neutral position in this study were greater than neck extension forces recorded by Helleur, et al (1985) in all neck positions. While the anthropometric data and test positions for the subject populations were similar, methods of subject

stabilization, arm positions, the angle of tension placed on the neck by the load cell, the duration of isometric muscle contractions, and the rest time allowed between contractions varied between studies. Foust et al (1973), did not include isometric lateral neck flexion in his data collection. Helleur tested extensor muscle contractions only from three positions of neck flexion or extension. Harms-Ringdahl et al (1988) tested variances in force developed by the neck extensors from five positions of neck flexion or extension.

Neck muscle contraction forces measured in this study not only exceeded those measured by Petrofsky and Phillips (1982) for all directions tested, but differed in the strength trend for maximum forces. While measured neck forces were greater in extension, than flexion than side bending in the present study (Figures 5 & 6), Petrofsky and Phillips measured greater neck flexion than neck extension than side bending forces. Differences in the results between the two studies may relate to load cells, subject positioning, or duration of contraction (brief vs sustained to fatigue) as mentioned earlier. However, differences in the size of the subject populations (n=60 vs n=4) and the training of the subjects prior to data collection should not be overlooked. The reliability, as noted in Table X (ICC = 0.87-0.90 with an observed reliability of $\bar{x}$ of 3 trials = 94.9 to 96.0%), of the ranges of neck strength observed in the large (n=60) sample population tested herein may be offset by the lack of experience the subjects had with the test contractions

as noted in the learning trend evident between trials (Figure 6). The limited ability to estimate forces of neck muscle contractions to a large population from the forces measured in the limited sample (n=4) tested by Petrofsky and Phillips may be improved by the isometric training that the subjects received, three times a week, for 3 to 5 weeks until they were able to produce consistent isometric contractions (coefficient of variance to sustained contractions was 3% - 5%). The Sp4 helmet, fit with dynamometers to measure neck contraction forces by Petrofsky and Phillips, is used extensively by the military for noise attenuation, impact protection, and easy fit for most subjects (Haley, et al, 1983), and probably allows for more comfortable measurement of prolonged forces than the head harness used in this study. The head harness, load cell apparatus used in this study had the benefit of being less expensive and easier to obtain than a helmet dynamometer for most clinicians.

While trends in neck contraction forces noted in the present study conflict with the work of Petrofsky and Phillips, the trends (neck extensor forces were greater than neck flexor forces) are consistent with the trends noted by Foust, et al (1973). Confidence in the similarities of the trends between the two subject populations may come from the larger sizes of the samples tested (n=30 and n=60), and the similarities between test position and angle of pull of the neck on the load cell. Reasons that neck extensor forces were

greater than neck flexor forces in this and Foust et al's study may be the mechanical advantage of the extensors (Foust, et al, 1973; Aspden, 1987) or variations in muscle fiber types between the muscle groups (Astrand, 1986). There may also be anatomical differences in blood circulation to the contracting muscles which can influence muscle fatigue, as suggested by Petrofsky & Phillips (1982), Biglund-Ritchie (1981), and Basmajian (1985).

Close comparisons between this study and muscle force estimates calculated by Moroney (1988), are not practical. In the present study isometric forces generated by muscle groups were measured, while Moroney calculated force estimates for individual muscles from measured myoelectric activity of superficial neck muscles. If the force estimates for individual muscles within a group of muscles (eg, neck flexors, extensors, or lateral flexors) were summed to represent the force for that group, then the estimated sums generated would greatly exceed the comparable neck muscle forces measured in this and other studies. Also force estimates were calculated for muscles that have been shown by other investigators to be non-contributory to isometric neck muscle contractions. Non-contributing muscles such as the platysma or the infrahyoids (de Sousa, 1964, as cited by Basmajian, 1985) are generally considered to act upon the mandible. These were included as lateral and forward neck flexors by Moroney. Another challenge to comparing forces measured in this work with forces estimated by

Moroney is the proximity of the eight surface recording electrodes placed around the circumference of the neck at the level of the C-4 vertebrae. These may have been subject to interference or crosstalk from unrelated muscles not directly under the electrode. This possibility was demonstrated by the variance in Moroney's coefficient of correlation between calculated muscle forces and measured myoelectric activity (range from 0.29 to 0.85).

The presence of learning trends between the first, second and third trials for all directions of neck contractions tested (Figure 6) suggests that the maximal isometric forces were not yet attained in three trials. There is less change between the second and third trials than between the first and second trials which may suggest that with continued trials, a force plateau may be reached. Using the combined mean of the latter two trials instead of the three trials may also produce a more representative value for force. A longer sampling window may have produced different results. According to Astrand (1986), approximately 4 seconds is needed to reach maximal isometric tension for most muscle groups and the duration of the isometric contraction should be about 6 seconds. In view of the neck muscle forces needed for quick response (Foust, et al, 1973), the data collected during brief contractions (< 2 seconds) and presented here is appropriate as it represents what neck muscle forces can be generated within a quick response. As exhibited by the learning trend between contractions, and as estimated by Gracovetsky (1981)

and Chaffin & Baker (1970), more cervical muscle force is potentially available for injury prevention.

There was no significant functional asymmetry measured between the two sides of lateral neck flexors (Fig. 5 & 6). Combined force means of three trials of attempted left and right lateral flexion was 159 N (sd 38.96 N) and 153 N (sd 36.46 N) respectively. This represents less than 4% variance between sides for an untrained subject population (n=60). The lack of functional asymmetry measured in the lateral neck flexors during brief isometric contractions, is consistent with the contractions forces measured by Petrofsky and Phillips (1982) during sustained left and right lateral isometric contractions. Their results for an isometrically trained subject population (n=4) were 86.50 N (sd 16.32 N) and 86.94 N (sd 16.12 N) for the left and right sides respectively, with a variance of less than 0.5% between sides. The lack of strength asymmetry of the lateral neck muscles in an untrained (non-athlete) population is consistent with a lack of trunk muscle asymmetry in normal, untrained athletes as cited by Andersson, et al (1988). As lateral trunk muscle asymmetry is evident in trained athletes (Andersson et al, 1988), it would be of interest to know whether strength asymmetry of lateral neck muscles is present in athletes trained in different sports.

In comparison to isometric lumbar muscle contraction forces calculated by Bean et al (1988) of 695 N for the erector spinae during isometric extension, the isometric cervical muscle contraction forces measured here were up to 391 N for cervical extension. McNeill et al (1980) measured mean isometric lumbar forces of 550 N for attempted extension and 400 N for attempted flexion. This again is approximately twice the mean isometric cervical forces of 236 N for attempted extension and 202 N for attempted flexion measured in this study.

Test-retest results

Variance in test-retest results (Table IX, t = 0.11 to -1.54) may be due to differences in the time of day that the two tests were conducted or due to normal diurnal intrasubject variation. Retest times for subjects were not standardized to coincide with initial test times. Petersen, et al, (1982), noted that grip can vary from 19-24% within a healthy, normal subject on a daily basis. Hill, et al (1989) reported that circadian specificity exists for sub-maximal exercise training and performance. Although, subjects in this study were untrained, a learning trend, as noted in Figure 6 for the sample population, between the neck trials was evident within each test. In the small (n=6) retest subpopulation, evidence of a learning trend between tests was

inconsistent as represented in Figure 5. Each subject varied (+) or (-) in each direction of neck contraction forces tested.

The small size of the retest subsample does not rule out further inconsistencies that might have become evident if a larger subsample was chosen.

Chapter 5

SUMMARY, CONCLUSION, AND RECOMMENDATIONS FOR FURTHER STUDY

Summary

The purposes of this study were: 1) to establish normative values for the isometric force developed by the neck muscles of the healthy adult male; 2) to determine whether the isometric force developed by the neck muscles was related to anthropometric measurements (eg, height, weight, neck length, girth, or curvature); 3) to determine whether grip strength and neck strength were correlated; 4) to compare isometric forces generated by the cervical spine during single and repeated muscle contractions; and 5) to determine if a functional asymmetry existed between the right and left lateral neck flexors.

This study included 60 healthy, adult, male, volunteers, ages 18-35. All subjects were able to complete the testing. Six subjects (10%) were randomly selected to return at a later date for retesting to evaluate test-retest reliability. Age and hand dominance were collected per subject report. Anthropometric measurements of subject weight, height, neck length, girth, and spinal curvature were measured while the subject was standing. Neck circumference was taken at the horizontal level of the spinous process of the C-7 vertebrae.

Neck length and curvature were measured from the inion to C-7 according to Rheault (1989). Isometric handgrip was tested on each side using a Lafayette dynamometer according to standards set by The American Association of Hand Therapists (1985). Each hand was tested three times and contractions lasted three seconds with a 60 second rest allowed between contractions. Isometric neck strength was measured with the subjects sitting in an adjustable chair. Subjects were stabilized to the backrest of the chair using three straps to limit substitution patterns of the head, neck, or trunk. Subjects were fitted with an adjustable head harness. The head harness was fitted with four D-rings, one for each side of the head which linked the head harness, via an adjustable chain, to a wall mounted load cell. The calibrated load cell measured the force of the isometric contraction. The load cell was interfaced with a signal amplifier and connected to a desk top computer. The signal was digitized at 2000 Hz, then collected and analyzed. The digital signal was converted to units of force through the use of calibration values. The calibration of the load cell was performed daily prior to data collection and checked before and after each subject. Subjects were instructed to exert pain-free isometric contractions of the cervical muscles. Contractions lasted for three seconds, and data were collected for the latter two seconds. Trials were repeated three times for each test direction, with a sixty second rest between each contraction. Test directions were flexion, extension, and right and left side bending.

Mean values for the forces generated by isometric neck muscle contractions were: right side bend, 152.90 N (sd 36.47 N); left side bend, 158.66 N (sd 38.96 N); flexion, 202.25 N (sd 48.57 N); and extension, 236.06 N (sd 48.44 N).

There was a weak correlation of neck girth with neck strength in all four directions tested ($p < 0.05$, $r=0.31$ to 0.35), and a weak inverse correlation between neck length and right lateral neck strength ($p < 0.05$, $r= -0.314$, $p = 0.015$). There was a weak correlation between body weight and neck extension strength ($r= 0.258$, $p = 0.046$).

Hand grip was not statistically correlated with ipsilateral or contralateral neck strength. There was no asymmetry of strength between the lateral neck flexors. A functional strength asymmetry between dominant and non-dominant grip strengths was noted, consistent with current studies (Petersen, 1989; Smith, 1989; Young, 1989).

Isometric cervical contraction forces within and between trials were calculated and compared. It was noted that the intensity of contractions increased between the first, second, and third trials, indicating the probability of a learning trend. This trend toward increased force exerted by successive contractions was consistent with each direction of force tested, but

independent of the sequence of the testing. This trend was also present with the retest subpopulation. For handgrip, there was not a consistent increase or decrease in the force generated during maximal contractions between the first, second, and third trials for either side. Test reliability for cervical testing was 0.92 to 0.96. Test reliability for handgrip testing was 0.85 for the dominant hand and 0.92 for the non-dominant hand.

Conclusion

Based upon the data collected in this study, the following conclusions may be made:

1) Normative data for isometric neck strength for the healthy, adult, male, ages 18-35 has been presented. This data was obtained using a simple testing method that can be replicated in a clinical setting.

2) Neck strength does not appear to be correlated to subject height, weight, neck length, or curvature. Neck strength is weakly correlated with neck girth taken at the C-7 level ($r=0.31$-0.35). These anthropometric characteristics are probably not useful as predictors of neck strength for the population tested.

3) Lateral neck strength appears to be unrelated to handgrip strength.

4) There appears to be evidence of a learning trend between the first, second, and third trials of isometric test contractions, as noted by increased forces generated by the successive contractions.

5) A functional strength asymmetry between the right and left lateral neck flexors does not appear to exist in the normal adult, male, population, ages 18 to 35.

Recommendations for Future Studies

The need for a reliable and effective method of objectively measuring normal neck contraction forces is important to the clinician who is assessing a subject's healing from injury or for assessing a subjects's capability for maintaining their head and neck in postures required by various work and leisure activities.

The method presented in this study offers potential in providing an easy, effective and reliable method for clinicians to measure neck contraction forces. Further studies that are needed include testing the number of times a neck muscle force should be tested to ascertain a representative, reliable

measurement of that muscle force. Test populations should be expanded to include both sexes and a broader age range. Data are also needed on normal strength ranges for athletes trained in specific sports, subjects involved in acitivites that are highly stressful to the neck, and in injury populations. Finally, the effectiveness of strength training programs for the cervical muscles needs to be evaluated.

APPENDIX A

CONSENT FORM

ISOMETRIC TESTING OF THE CERVICAL SPINE IN COLLEGE AGE MALES, AGES 18 TO 35

I, ______________________________________,
Subject's Name

agree to participate in the research study under the direction of Julie I. Keller, BSPT, and her research assistants.

I understand that I will spend approximately 30 minutes in the Wenner-Gren Biodynamics Laboratory or the Physical Therapy Laboratory at Annex II at the University of Kentucky. I understand that I will not be paid for participation in the study. The purposes of the study have been explained to me as follows:

--Isometric neck strength of the healthy adult male will be studied in order to: 1) establish normal values for isometric neck strength, 2) investigate whether muscle torque values of the cervical spine differ between one and many contractions, 3) determine whether hand dominance and neck strength are related, and 4) determine if strength is related to neck measurements.

I understand that participation in this study will involve the following procedure:

--During the evaluation I will wear my own clothing.

--I will be asked to perform maximal isometric contractions of certain neck muscles and of my dominant hand grip.

I should feel no discomfort due these procedures and the investigators foresee no risks or unusual discomforts for the subjects involved in this study.

The results of these tests and measurements will be confidential.

I understand that in the event of physical injury resulting from the research procedures in which I will participate, no form of compensation is available. Medical treatment may be provided at my own expense or at the expense of my health care insurer, which may or may not provide coverage. If I have any questions, I should contact my insurer.

I understand that significant findings developed during the course of this research which may relate to my willingness to continue participation will be provided to me.

Participation in this study is voluntary; refusal to participate will involve no penalty or loss of benefits to which I am otherwise entitled. I understand that I may discontinue participation at any time without penalty or loss of benefits to which I am otherwise entitled.

Subject's Signature Date

Witness' Signature Date

I have explained and defined in detail the research and procedures in which this subject will participate and have provided the subject with a copy of this informed consent document.

Principal Investigator Date

APPENDIX B

SUBJECTS INSTRUCTIONS FOR HANDGRIP TESTING

1. Position the subject
   --seated in biodex chair
   --humerus fully adducted, in neutral rotation
   --elbow flexed to 90 degrees
   --forearm and wrist in neutral rotation
   --position of dynamometer handle adjusted per subject comfort

2. Instruct subjects that they should:
   --not let their hand or dynamometer rest on their leg while testing
   --squeeze the handle of the dynamometer as hard as they are able to for three seconds on the count of three

3. Allow subjects to practice the handgrip test by exerting one submaximal attempt to squeeze the dynamometer to demonstrate understanding of the instructions and the ability to perform the test.

4. Count to three.

5. Give maximum encouragement for the subject to squeeze the dynamometer as hard as they can.

6. After three seconds tell the subject they should relax their hand and rest for sixty seconds.

7. Record dynamometer reading on subject information sheet.

8. Repeat test up to three times on each hand, alternating hands tested between dominant and non-dominant sides.

APPENDIX C

SUBJECT INSTRUCTIONS FOR ISOMETRIC NECK STRENGTH TESTING

1. Position the subject in the biodex chair
   --subject is seated, legs are relaxed and not braced against the footrest of the chair
   --stabilize subject with three stabilization straps
   --instruct subjects to fold their arms across their chest for the test
   --adjust head harness to fit, reinforce with additional D-ring strap
   --for test contractions, subject's head will be in the relaxed, neutral, vertical position for each subject

2. Prior to collection of force data for the isometric neck muscle contractions
   --attach adjustable chain to the appropriate D-ring on the head harness for the direction to be tested
   --take up slack in chain
   --instruct each subject in the direction of force that will be tested (flexion, extension, or right or left lateral bending)
   --remind subject that they are to exert the maximum comfortable, isometric contraction that they are able to exert and that if they feel discomfort during the contraction they are to immediately stop the contraction and notify the tester at that time
   --instruct subjects that they should exert the maximum comfortable, isometric contraction that they are able to exert on the count of three, and that they are to sustain that contraction for three seconds
   --instruct subjects to close their eyes during the test contractions

3. Allow subject to generate one submaximal contraction for the direction to be tested, to demonstrate understanding of the instructions and the ability to generate the appropriate muscle contractions.

4. Count to three.

5. Offer maximal encouragement for subject to exert their maximal, comfortable, isometric neck muscle contraction for three seconds.

6. Instruct subjects to stop the contraction and relax for sixty seconds.

7. Repeat test two more times for each test direction.

8. Reposition chair after three trials in each direction.

9. Repeat steps 2-8 until all four directions are tested.

APPENDIX D

SUBJECT INFORMATION SHEET

NAME:______________________________ DATE:__________

SS#:_____________________ SUBJECT #:__________

HT:__________ WT:__________ CAL. FILE:__________

NECK: LENGTH:______ GIRTH:______ DOM. HAND:_____

GRIP: DOMINANT: _____lb NON-DOM: _____lb

_____ _____

_____ _____

CODE: _____-R1 _____-L1 _____-F1 _____-E1

2 2 2 2

3 3 3 3

ANALYSIS

TRIAL	INTERVAL REF:	IT (lbs)	IG (lbs/sec)
--R1	(____-____)	________	________
-- 2	(____-____)	________	________
-- 3	(____-____)	________	________
--L1	(____-____)	________	________
-- 2	(____-____)	________	________
-- 3	(____-____)	________	________
--F1	(____-____)	________	________
-- 2	(____-____)	________	________
-- 3	(____-____)	________	________
--E1	(____-____)	________	________
-- 2	(____-____)	________	________
-- 3	(____-____)	________	________

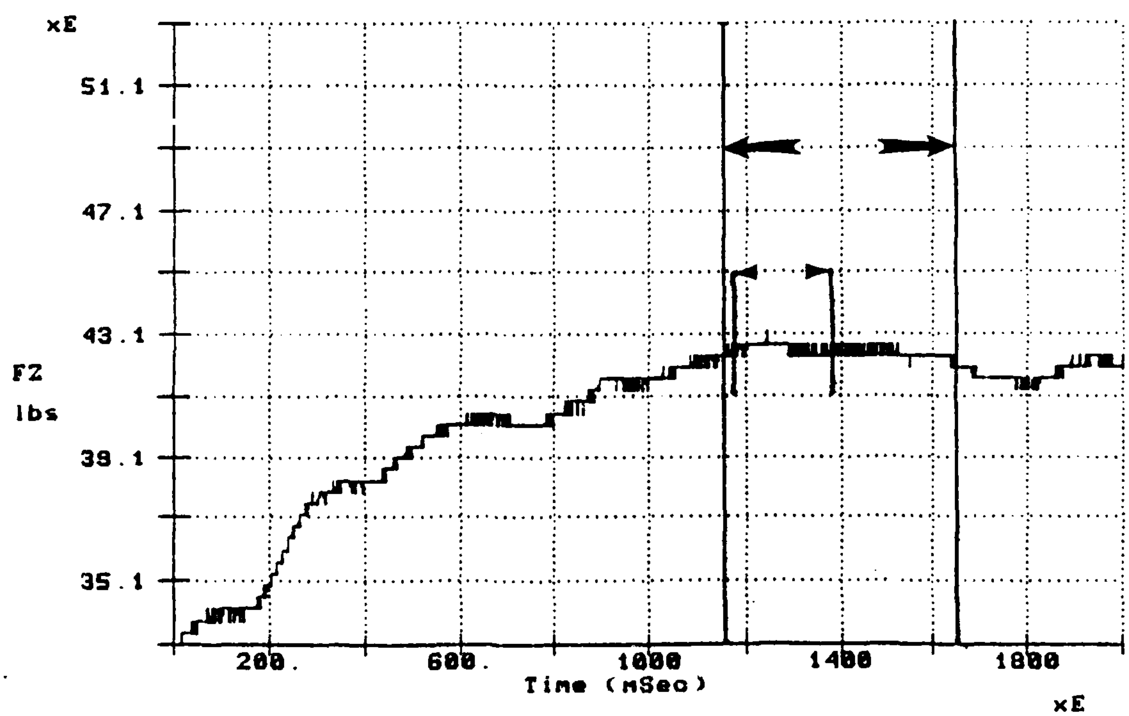
APPENDIX E

EXAMPLE OF TWO-SECOND DATA-COLLECTION WINDOW

–The highest 0.5 second of the force-vs-time curve which contained the consistently highest force was used for analysis. This window was determined using cursors (see arrows). The area under the curve was integrated with respect to time using computer assisted analysis. This resultant force was used here to represent the "average" isometric force for that trial.

–The greatest force that was maintained for a minimum of 0.05 seconds was also determined using cursors (see arrowheads), integrated, and termed termed the "instantaneous peak force" for that trial.

–Force spikes that were generated for less than 0.05 seconds were ignored due to the possible presence of signal artifact.



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VITA

[redacted]

Education: University of Colorado
Denver, Colorado
School of Physical Therapy
Bachelor of Science Degree, 1973

Professional: Staff Physical Therapist
Eisenhower Osteopathic Hospital
Colorado Springs, Colorado
October 1973 - July 1977

Staff Physical Therapist
Memorial Hospital
Colorado Springs, Colorado
February 1979 - December 1983

Staff Physical Therapist
United States Air Force
January 1984 to present

Julie Riedel Keller

Julie Riedel Keller